CONCENTRATION VERSUS MASS FLOW

A supporting document for the
UC Center for Water Resources (http://www.waterresources.ucr.edu)
Nitrate Groundwater Pollution Hazard Index

A critical issue in protecting ground water from degradation by agricultural sources of N is whether it is more important to reduce the NO_3 concentration or the total mass of NO_3 in the water percolating below the root zone. The obvious answer is to have low numerical values for both criteria. However, a low concentration may not lead to a low mass emission or vice versa. If the low concentration is achieved by a large amount of water flow, the low concentration could be associated with a high amount of mass flow.

The possibility of having high chemical mass transport with a low concentration can best be described by considering salts dissolved in the water. As water is lost from the soil through evapotranspiration (ET), the salts are left behind and become concentrated. Assuming no precipitation or dissolution of salts in the soil, the concentration of salts in the water leaving the root zone (C_d) is related to the concentration of the salts in the irrigation water (C_i) by the following equation:

$$C_d = C_i/LF;$$

where LF is the leaching factor and is defined as:

$$LF = (AW–ET)/AW,$$

where AW is the applied water that infiltrates the soil. The amount of deep percolation carrying chemicals to the ground water is equal to AW–ET. Thus, the concentration of chemical in the water leaving the root zone is inversely proportional to the amount of deep percolation. A low concentration can be achieved by managing water to create a high amount of deep percolation. Thus, a low concentration is not a good indicator of the potential ground water degradation. Although the example has been used for salts, the same principle can apply to other chemicals that can be diluted by virtue of having high amounts of deep percolation.

Special consideration must be given to nitrogen, however, because of the chemical transformations that are possible. For example, a clay layer, which restricts water flow, could contribute to a high NO_3 concentration by restricting the leaching fraction as reported for salts. Conversely, the clay layer could create an anoxic condition that causes denitrification and lower NO_3 concentration. Thus, the NO_3 concentration could be increased or decreased depending on which mechanism predominated. Both mechanisms, however, reduce the mass transfer of NO_3 toward ground water.

Letey et al. (1977) reported the results of an extensive investigation on nitrate-nitrogen in agriculture tile drain effluents in California. No correlation was found between the average NO_3 concentration in the drain water and the amount of fertilizer N application. However, there was a significant correlation between the annual mass discharge of NO_3 and the amount of fertilizer N application. No correlation was found between the average NO_3 concentration in the drain water and the total annual amount of drainage water. However, there was a significant correlation between the annual mass discharge of NO_3 and the total annual amount of drainage water.

The effect of leaching rates on NO_3 concentration in a soil profile without restricting layers causing denitrification is illustrated by the results of an experiment conducted at UC Davis. The experiment investigated the effects of nitrogen and water applications on nitrate leaching and nitrate concentration below the root zone. The results as reported by Tanji et al. (1979) are summarized in Table 1. Note that the nitrogen concentration in the soil at the depth of 3 meters increases with increasing fertilizer application as expected. However, for a given N application, the N concentration at the 3-meter depth is higher when lower water applications were made. Conversely, the calculated amount of N leaching is very high for the highest water application and very low for the lower water applications. If one only had the N concentration to monitor the effectiveness of the management practice on ground water degradation by N, they would arrive at a drastically erroneous conclusion.

The key question is as follows. From a ground water quality perspective, is it better to have a larger volume of leachate water with a lower NO_3 concentration or a smaller leachate volume of water at a higher NO_3 concentration when the total mass of NO_3 is greater in the former case? If there were complete mixing of the leachate with the total volume of the aquifer, the lower mass load would be the obvious answer. However, complete mixing does not occur, so the question remains open.

Whether the impact of NO_3 concentration or the impact of mass on ground water quality is greater can be debated. A conclusion that is well supported by research findings and scientific principles is that the concentration is not a valid indicator of good versus bad agricultural management practices. This conclusion creates a dilemma. The concentration is relatively easy to measure whereas the mass flow is very difficult, if not impossible, to accurately measure. Therefore, the concentration is measured and interpretations of whether management is good or bad are often based on concentration. Erroneous conclusions are possible.

Since monitoring for possible ground water degradation from nonpoint sources is expensive and can possibly lead to faulty conclusions, is there an alternative? Since the basic chemical and physical factors related to transport are reasonably well understood, one can focus on relating management factors to the potential for ground water degradation. Since different soils and crops have different intrinsic vulnerabilities or hazards for ground water degradation, one can reduce the overall burden and potential cost to the farmer by identifying the relative level of hazard on each field. The greatest attention and possibly resource allocation can be on the most hazardous fields with less attention to the low hazard fields.

References:

Letey, J., J.W. Blair, Dale Dewitt, L. J. Lund, and P. Nash. 1977. Nitrate-nitrogen in effluent from agricultural tile drains in California. Hilgardia 45(9):289-319.

Tanji, K. K., F. E. Broadbent, M. Mehran, and M. Fried. 1979. An extended version of a conceptual model for evaluating annual nitrogen leaching losses from cropland. J. Environ. Qual. 8:114-120.

Table 1.

Relationship between Fertilizer Application and Irrigation on N Concentration below the Root Zone

N Application kg/ha	**Irrigation** cm	**N Conc.** mg N/L	**Calc. N Leached** kg/ha
0	100	8.6	13.2
90	100	12.4	20.2
179	100	16.9	26.8
358	100	32.1	66.7
0	60	9.4	0.52
90	60	12.1	0.78
179	60	15.4	1.03
358	60	35.9	2.95
0	20	16.2	0.0
90	20	27.2	0.0
179	20	34.0	0.0
358	20	47.0	0.0